Issues in HEP related to Quantum Machine Learning (QML), decoherence and quantum foundations.

Snowmass Computational Frontier Workshop

10-11 August 2020

Andreas Albrecht (QMAP/UC Davis)
with
Andrew Sornborger and Patrick Coles (LANL)

LA-UR-20-26176

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Part 1: Big picture

Part 2: Examples

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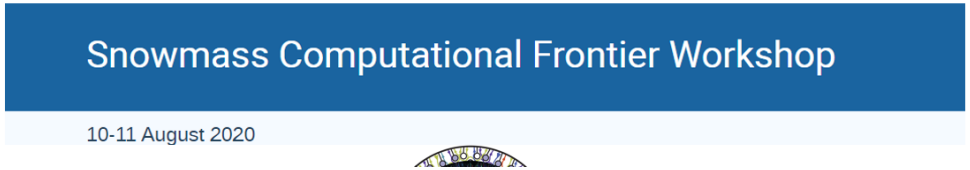

QML: Machine learning with quantum computers

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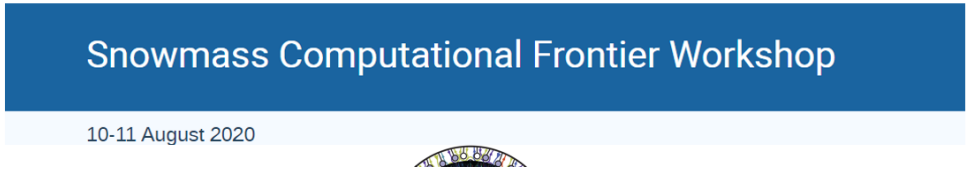

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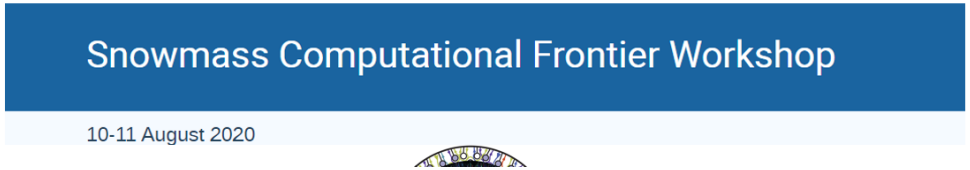

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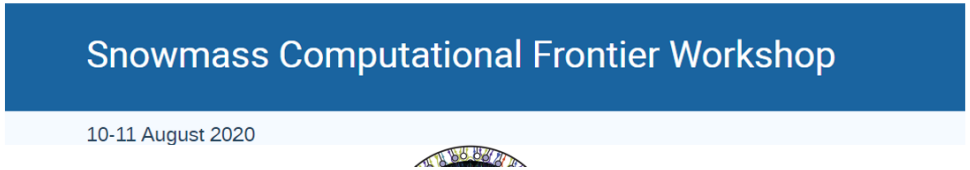

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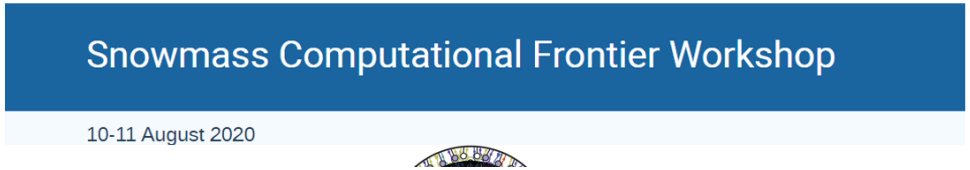

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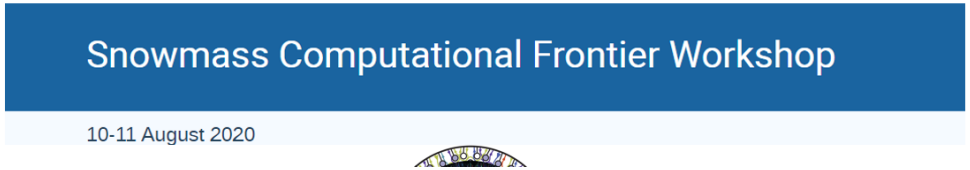

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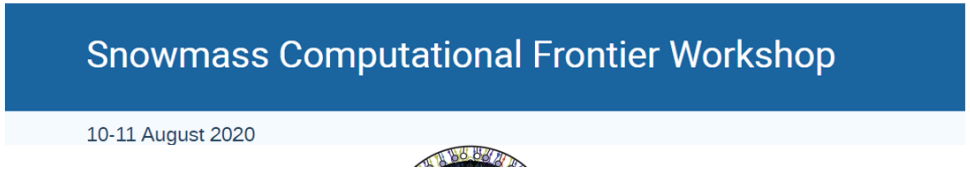

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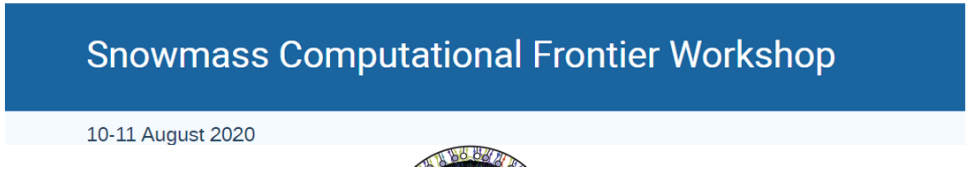

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The QIS boom is providing an expanding array of systems where these phenomena can (and must be) studied

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Philo…phical ra…bl…ings

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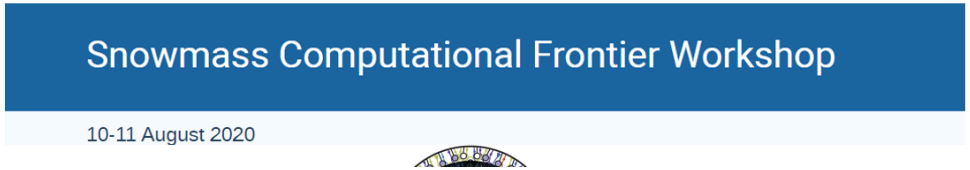

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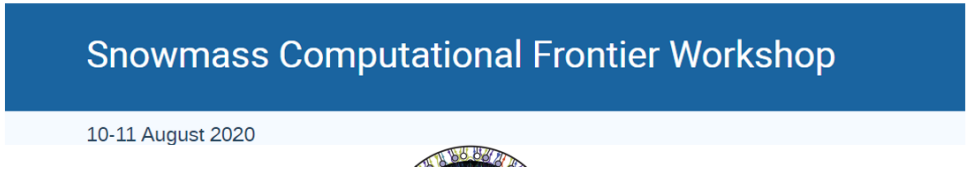

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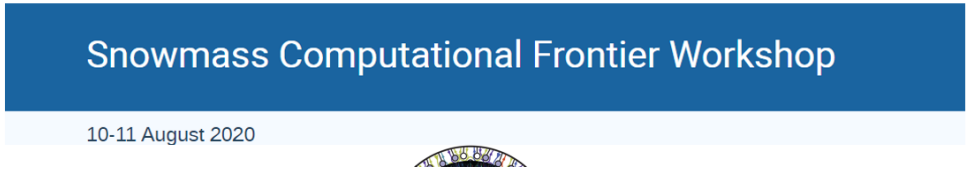

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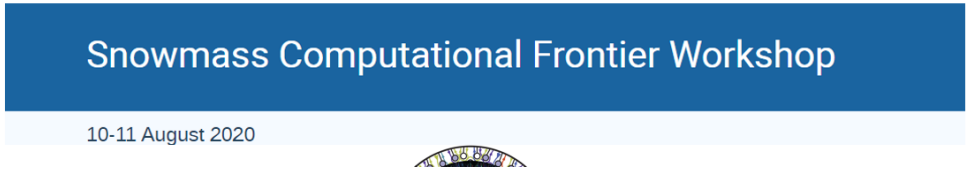

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QML: Machine learning with quantum computers

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System learning (Holography/quantum gravity)

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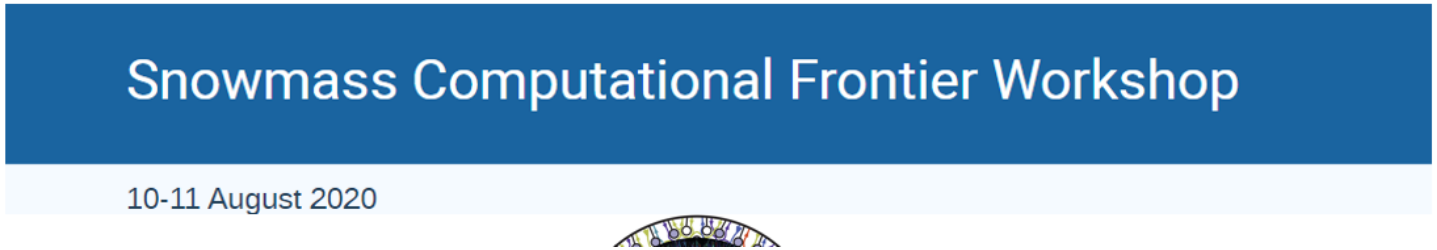

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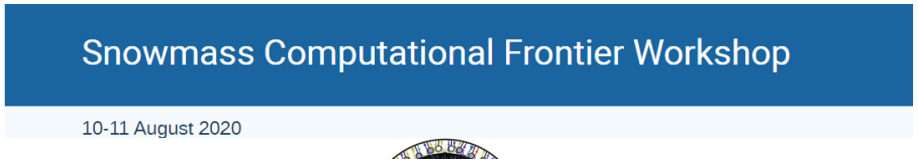

Part 2: Examples

1) Decoherence and einselection away from the Markovian limit (Adapted Caldeira Leggett Model, ACL)
   The "copycat process", arrow of time

2) Einselection, subsystems and locality on a quantum computer
   Emergence of locality

3) Using quantum assisted machine learning for system discovery

Our collaboration:

Arsalan Adil (QMAP/UCD)
AA (QMAP/UCD)
Andrew Arrasmith (LANL)
Rose Baunach (QMAP/UCD)
Patrick Coles (LANL)
Zoe Holmes (LANL)
Andrew Sornborger (LANL)
Bin Yan (LANL)
Wojciech Zurek (LANL)

Sponsored in part by a DOE Quantum Information Science Enabled Discovery (QuantISED) grant at LANL/QMAP
AA & Sornborger as Leads

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We've adapted the Caldeira-Leggett model (std toy model for exploring decoherence) to numerical applications

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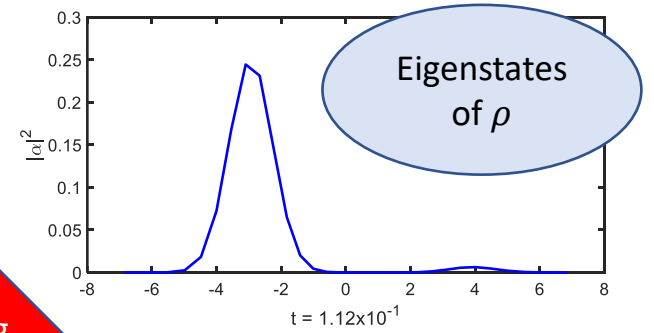
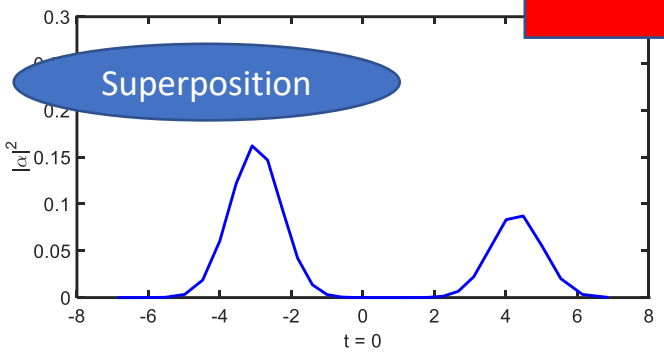
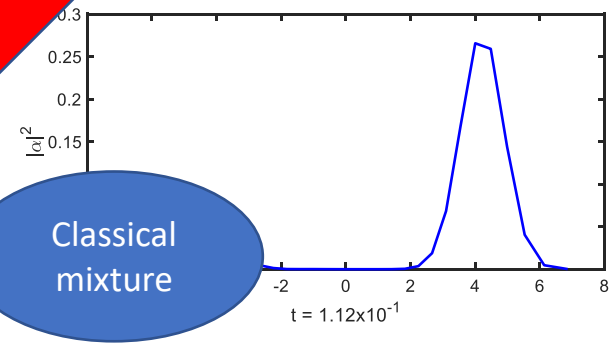
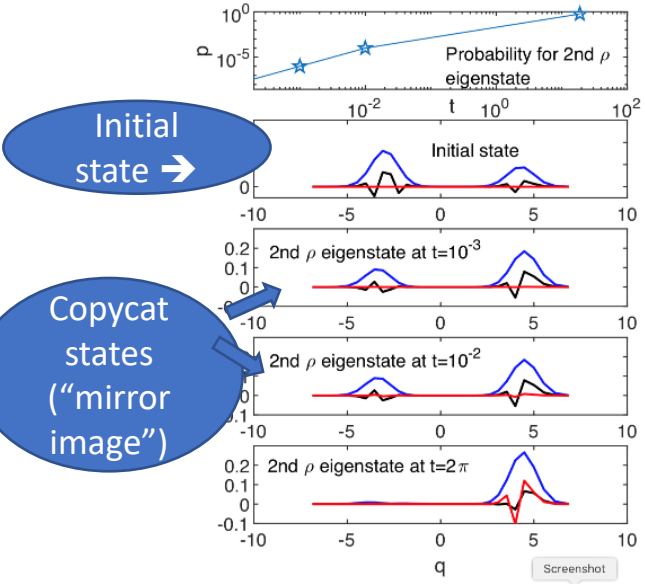


Einselection (Increasing Entropy)





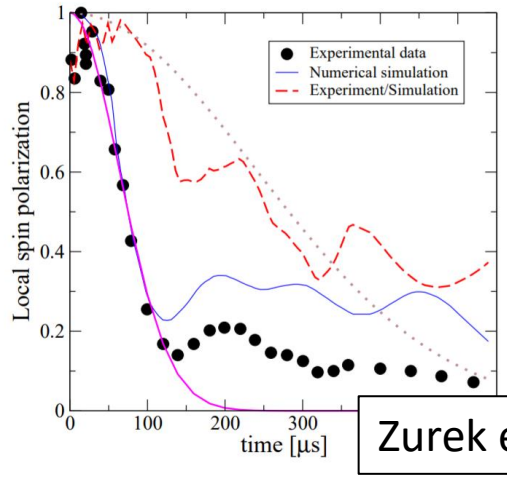
Unitary adaptation of the Caldeira-Leggett Model



Early transition to einselection

Copycat states appear to be a very generic starting point for the einselection process

Links to NMR work



Zurek et al

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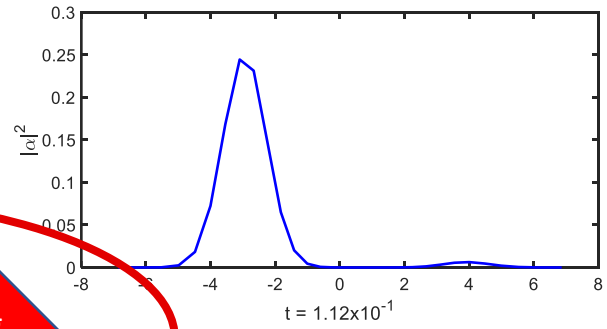

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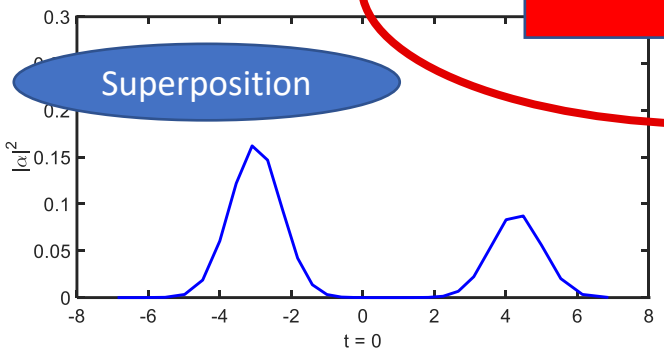
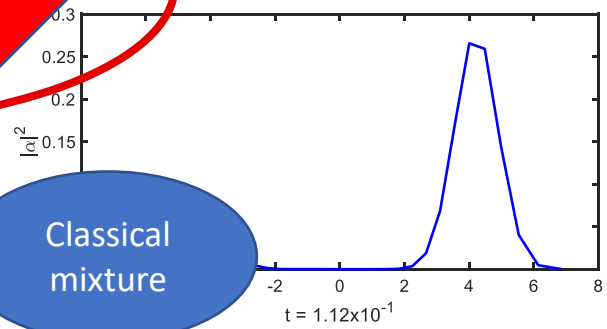


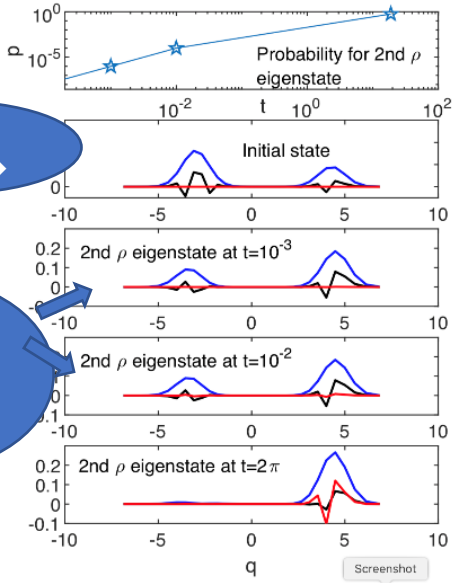
Superposition



Classical mixture

Unitary adaptation of the Caldeira-Leggett Model

Initial state ➔

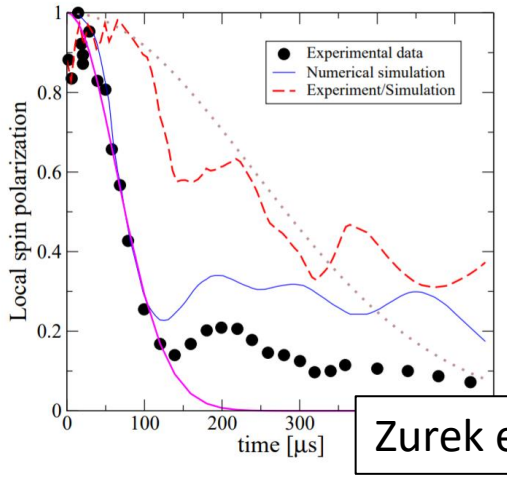


Copycat states ("mirror image")

Early transition to einselection

Copycat states appear to be a very generic starting point for the einselection process

Links to NMR work



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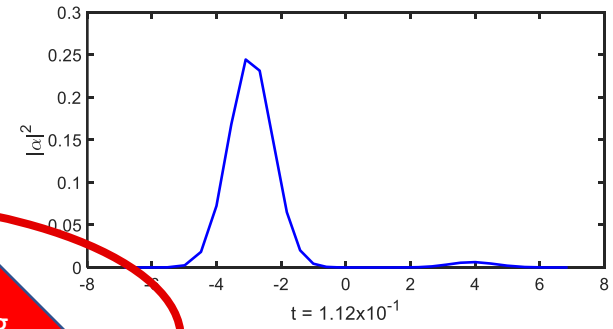

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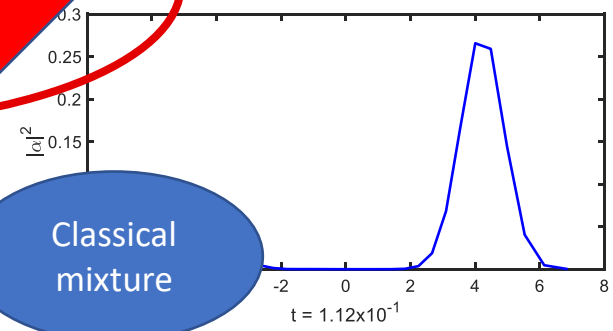
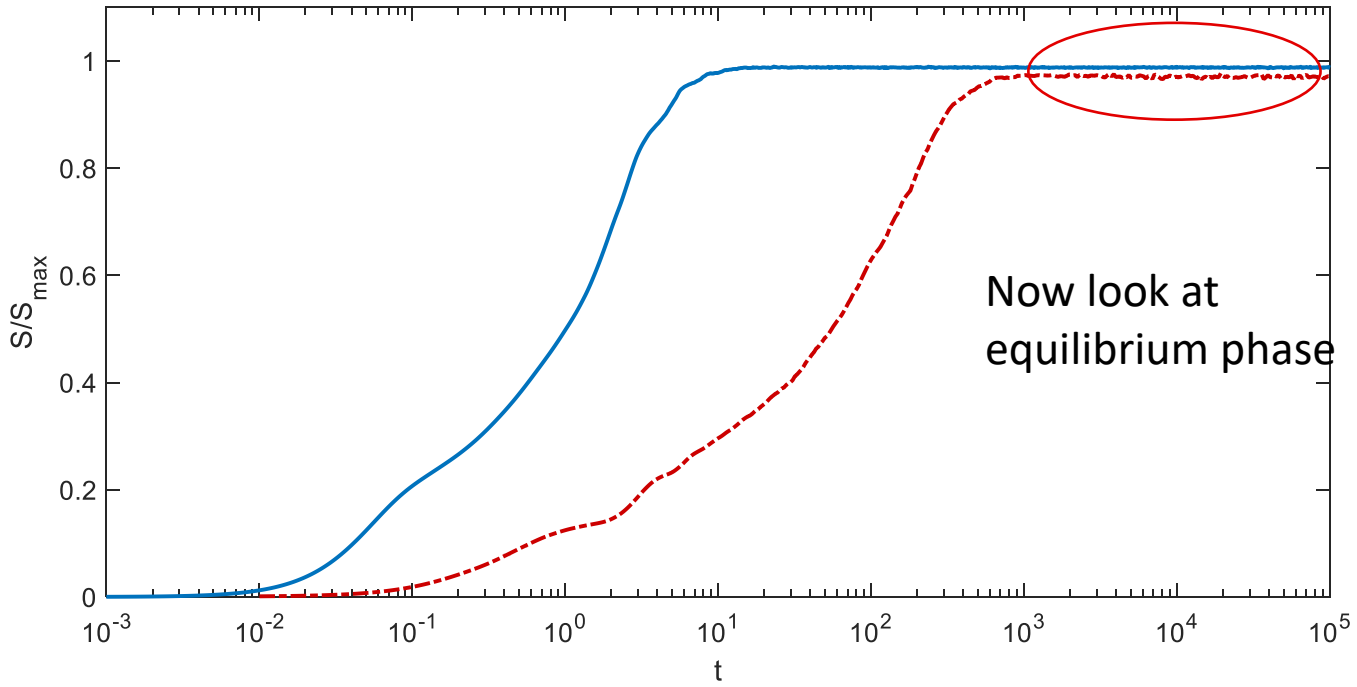


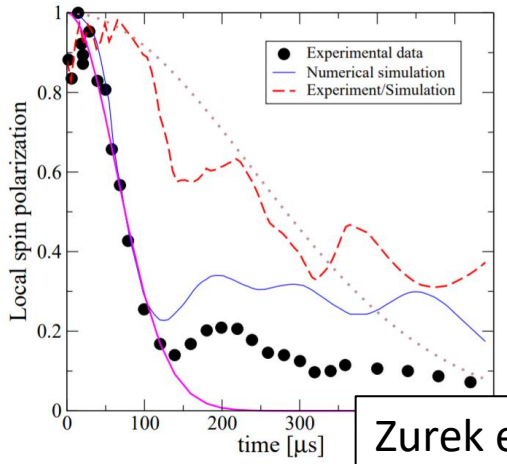
Classical mixture

-Leggett Model



Now look at equilibrium phase

Links to NMR work



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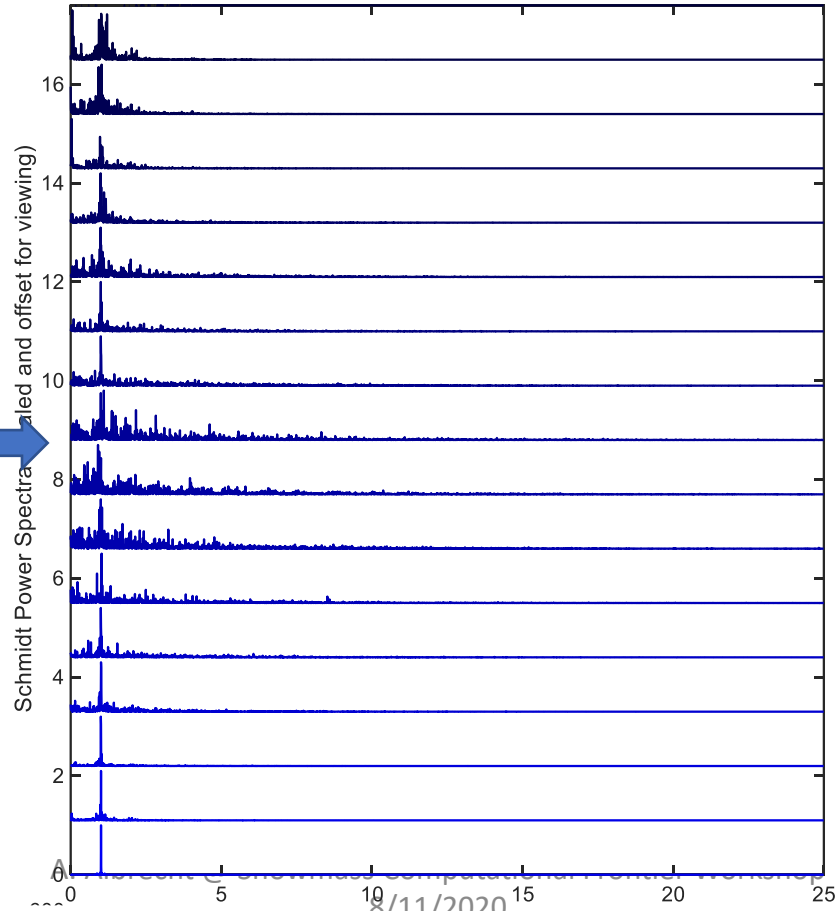
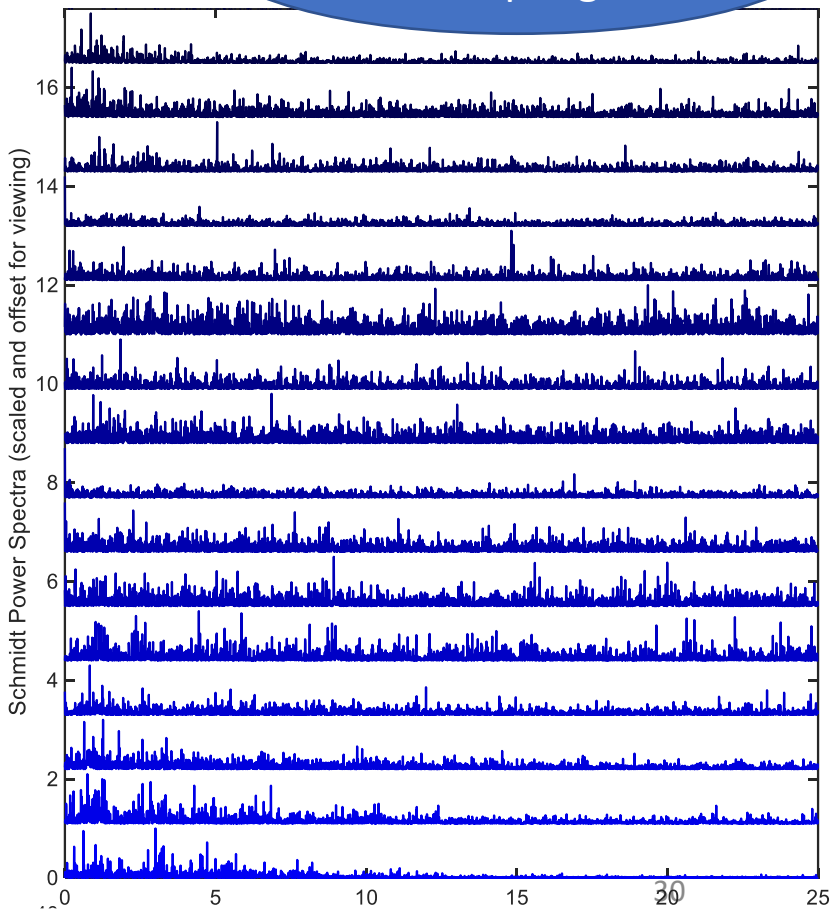
iii) <u>Can einselection happen in eqm?</u>

Peaks in these frequency power spectra of ρ eigenstates indicate persistence of some degree of einselection in eqm in the weak coupling case

Weak coupling



But not for strong coupling

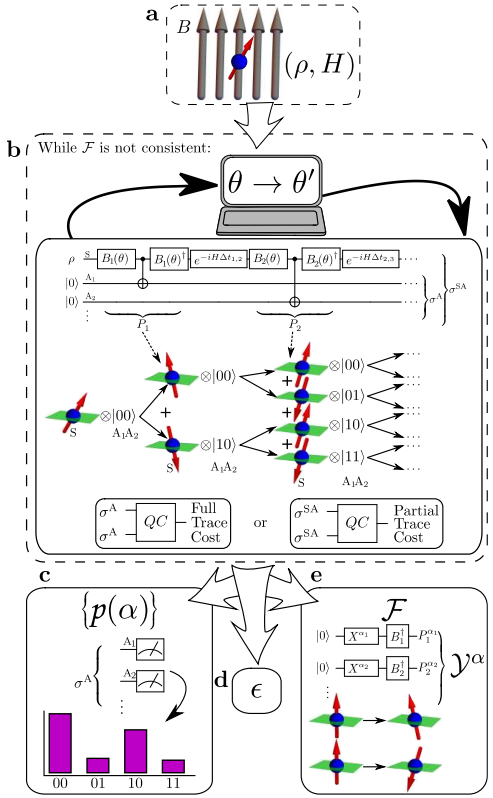


2) Einselection, subsystems and locality on a quantum computer

Consistent Histories:

Quantum History → Consistent → Classical Probabilities Make Sense

Consistent Histories:
- Crucial to understanding probability in HEP and cosmology
- Removes conceptual problem of identifying probabilities in quantum systems
- Relates to subsystems, separability and locality of fundamental physics

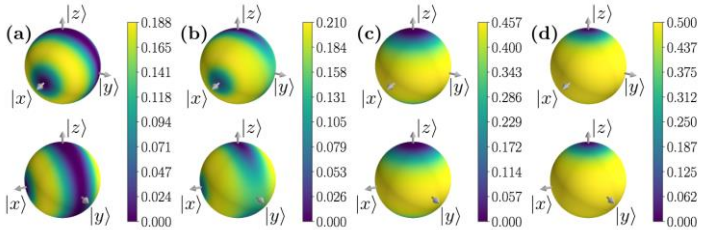


Studying consistent histories on QCs

Arrasmith, Cincio, Sornborger, Zurek, Coles, *Nat. Commun.*

- Implemented quantum algorithm for determining consistency
- Used machine learning to find consistent event descriptions
  ➔ find the "true subsystems" of the QC

Chiral Molecule, Quantum to Classical Transition



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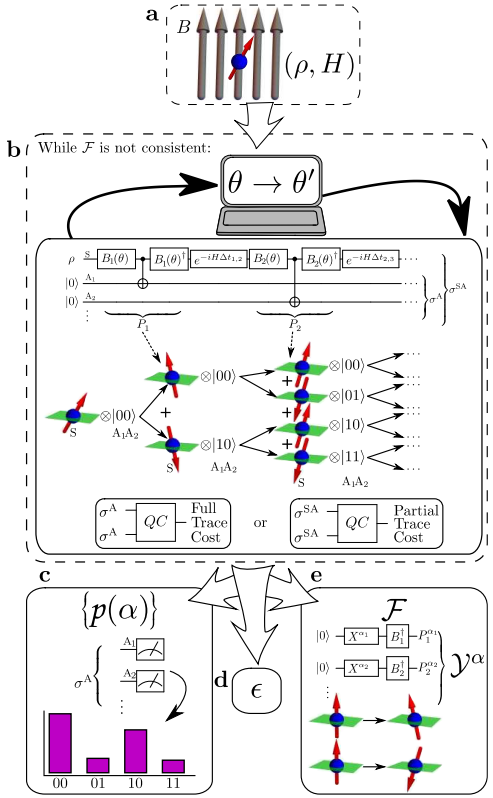
"quantum foundations"



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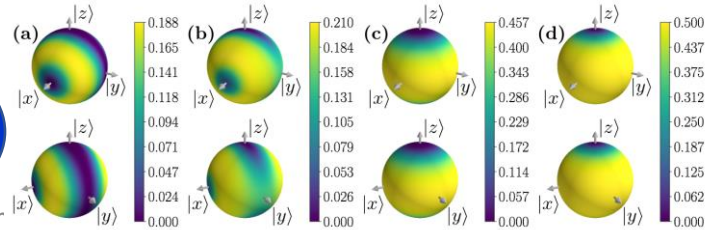

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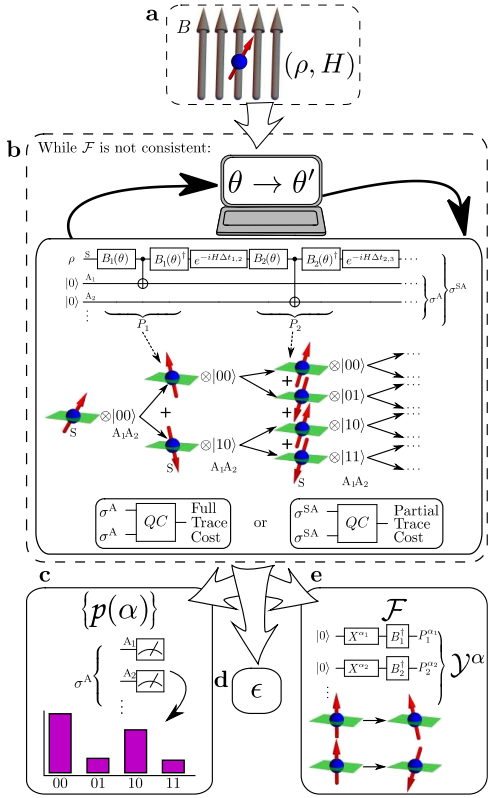

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Locality

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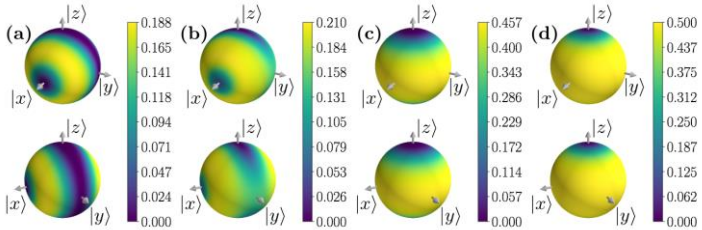


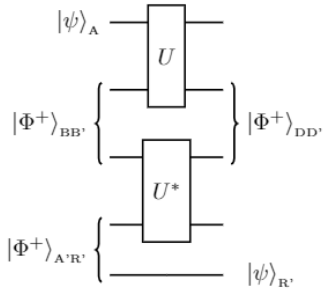
3) Using quantum assisted machine learning for system discovery

New project in progress

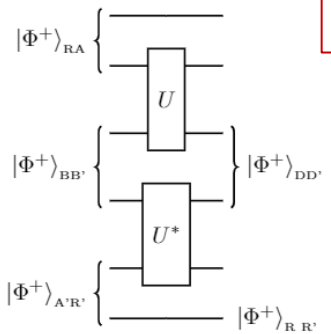
i) If only certain information is available from a unitary system, what tools can we use to try to infer the full unitary?

ii) Are there bounds on what we can learn about the unitary?

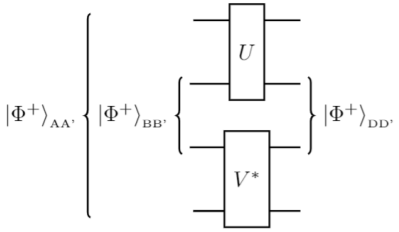
We are working to develop decoding protocols and cost functions to develop operational tools to address these questions, and to connect with existing literature on QML



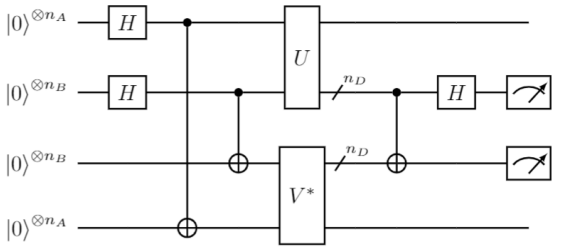
(a) Teleporting Specific State



(b) Teleporting Bell State



(a) General Schematic



(b) Explicit Circuit

Potentially relevant to quantum Black Holes

Issues in HEP related to Quantum Machine Learning (QML), decoherence and quantum foundations.

Snowmass Computational Frontier Workshop

10-11 August 2020

Part 1: Big picture

Part 2: Examples

- ➔ The current "QIS era" provides numerous opportunities for explorations of fundamental importance to HEP
- ➔ We are only beginning to scratch the surface